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PROVISIONAL SPECIFICATION

Electrical Arrangements for Measuring Small Movements

We, SIEMENS BROTHERS & CO. LIMITED, of Caxton House, Tothill Street, Westminster, London, S.W.1, a Company registered under British Law, and FREDERICK TURNER, of "The Crest", Shooters Hill, London, S.E.18, a British subject, do hereby declare the nature of this invention to be as follows:—

This invention relates to electrical arrangements for measuring small movements between two points along or within a body or between two bodies and is particularly concerned with arrangements employing a "null" method of operation in which the extent of a movement to be measured is determined by or is proportional to the extent of an adjustment required to restore a condition of balance in an electrical network which has been unbalanced as a result of said small movement. The arrangements of the invention find an especial application in connection with the measurement of torsion in a rotating shaft from which, given other factors, the transmitted horse-power can be calculated.

In the present invention arrangements are provided which include a pair of similar transformers fixed independently of the body and having their magnetic circuits individually and respectively completed over air-gaps which are caused to vary inversely as a result of a movement or variation of movement between two points of or within a body or between two bodies to bring about an unbalanced electrical condition in an electrical network including the secondary windings of the transformers, and means which is adjustable to restore said balanced condition, the extent of the adjustment required being a measure of the said movement or variation. The primary windings of the two transformers are connected to an alternating or an interrupted direct current supply, and with the former supply if a direct current instrument is eventually to be operated to indicate a movement or variation a rectifying arrangement or the equivalent will be included in circuit with the instrument. With an interrupted direct current supply it is also preferable to provide interrupting means in the circuit of such an instrument to disconnect half-cycles of current consequent on the opening or closing of the primary circuit. The secondary windings are connected in such relationship with one another that when the air gaps are equal, equal E.M.F.'s are produced in both windings and a condition of balance exists to be disturbed by a variation of the air-gaps by reason of a said movement whereby a preponderating current will exist in one of them, the difference current being a measure of the movement. The said means is adjustable to restore the E.M.F.'s to a condition of balance.

The said means may consist of electromagnetic arrangements which on adjustment can be made to produce current conditions to counter the said preponderating current, or alternatively it may consist of electrical arrangements which involves a purely electrical balancing of the secondary circuits.

For example in the former case the secondary windings of the transformers may be connected in series but in opposite senses. So long as the air-gaps and therefore the reluctances of the two magnetic systems are equal the E.M.F.'s across the windings will be equal and opposite. An inverse variation of the air-gaps and therefore of the reluctances of the magnetic systems results in an unbalance of the E.M.F.'s across the secondary windings with a consequential flow of current the value of which is a measure of the movement bringing about the variation of the air-gaps. The secondary and primary windings of these transformers may be connected respectively in series with similarly arranged secondary windings and primary windings of a further pair of transformers having similar characteristics to one another. These further transformers both have their magnetic circuits completed through a common magnetic member over intervening air-gaps, this common magnetic member being adjustable, such as by a micrometer screw, inversely to vary these air-gaps and thus the

relative reluctances. Thus the common magnetic member can be adjusted to produce an unbalance of the E.M.F.'s across the secondaries of the further transformers so that the consequential current flow is of such a value as to counter any current arising in the secondaries of the first pair of transformers, such a condition being indicated by an indicating instrument in the secondary circuit giving a zero reading. The extent of adjustment of the micrometer screw necessary to bring this about is indicative, and may be arranged to give a direct reading, of the extent of the movement measured.

In the latter arrangements mentioned above in which a purely electrical balancing is employed the secondary windings of the first mentioned transformers may be connected in series and in similar senses with one another and with a potentiometer, an indicating instrument being connected between the midpoint of the windings and the tapping point of the potentiometer, to form a resistance bridge network. Thus a preponderating E.M.F. in one of the secondary windings will produce a current flow which will be indicated on the measuring instrument, and the potentiometer can be adjusted until a zero reading is obtained, the extent of the adjustment, which may also be carried out by a micrometer screw, giving an indication, and it may be a direct reading, of the extent of the movement which brought about the unbalance.

The said first mentioned pair of transformers may be arranged closely together and may be annular and surround the body, such as a shaft, or bodies, the application to a shaft being particularly referred to in a specific embodiment hereafter. Each transformer is contained in a casing of magnetic material, the casings, however, not completely surrounding the windings but being open on that side facing the shaft. Where the transformers are in close juxtaposition a single exterior casing for both transformers may be used having a magnetic partition therein dividing the transformers and providing a common magnetic path for both. On the shaft adjacent and clearing each casing one on each side of the opening therein are annular members of magnetic material having teeth which overlap each other, with air gaps intervening, one member being fixedly associated with the shaft at one of the two places between which the twist is to be measured whilst the other is fixed to the shaft adjacent the transformers. Thus the magnetic circuits of the transformers are completed over the gaps between the casings and the annular magnetic members and between the teeth of the latter. Where the transformers are mounted in close juxtaposition a common middle magnetic annular member adjacent and co-operating with the common portion of the casing may be used between the outer magnetic members associated with the shaft at the said places, the middle member having teeth on each side of it co-operating with the teeth of the outer annular members. If the places on the shaft between which the twist is to be measured is greater than that required between the outer magnetic members, the latter may be secured to the ends of rigid sleeves over, and having their other ends fixed to, the shaft at the said places. With this arrangement the air-gaps between the outer magnetic member nearest the end of the shaft to which power is applied and the middle member increase with the application of power whilst those associated with the other outer member and middle member decreases, and *vice versa* on a decrease of applied power, so that the relative reluctances of the magnetic systems of the two transformers are varied inversely to one another.

Dated this 12th day of February, 1945.

SIEMENS BROTHERS & CO. LIMITED.
By their Attorney,
F. A. LAWSON.
For Selves and Co-Applicant.

COMPLETE SPECIFICATION

Electrical Arrangements for Measuring Small Movements

We, SIEMENS BROTHERS & CO. LIMITED, of Caxton House, Tothill Street, Westminster, London, S.W.1, a Company registered under British Law, and FREDERICK TURNER, of "The Crest", Shooters Hill, London, S.E.18, a British subject, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to electrical arrangements for measuring small relative movements between two places along or within a rotative body and is particularly concerned with arrangements employing a

"null" method of operation in which the extent of a movement to be measured is determined by or is proportional to the extent of an adjustment required to restore a condition of balance in an electrical network which has been unbalanced as a result of said small movement. The arrangements of the invention find an especial application in connection with the measurement of torsion in a rotating shaft from which, given other factors, the transmitted horse-power can be calculated.

In the arrangements of the present invention a relative movement between two places along or within the body brings about an alteration of the reluctance of a magnetic flux path associated with the body. This flux path is included in the magnetic circuit of a stationary open-cored transformer which has its primary winding traversed by a varying current, and therefore, a variation in the reluctance of the flux-path will bring about a corresponding variation of the potential appearing across the secondary winding of the transformer. By the provision of means which is adjustable to nullify any change in potential consequent on such a relative movement, that is, whereby the potential or change of potential produced thereby at two points in the secondary circuit is restored to that prevailing prior to the movement, a measure of the extent of the movement is obtainable.

The arrangements may include a single stationary transformer, the potential or potential change occurring at two points of the secondary circuit as a result of a relative movement and which is to be nullified, being derived directly from the secondary winding of the transformer. The said means may include a further transformer having its primary winding traversed by a current similar to that traversing the primary winding of the stationary transformer, and its secondary winding connected serially with but in opposite sense to the secondary winding of the stationary transformer, the reluctance of the magnetic circuit of the further transformer being adjustable to correspond with any change in the reluctance of the magnet circuit of the stationary transformer so that a potential appearing at two points of the secondary circuit in consequence of the latter change may be cancelled, the extent of the adjustment being a measure of the relative movement.

Alternatively two stationary transformers may be employed, the magnetic circuits of the transformers including individual flux paths associated with the body, and being arranged so that the magnetic reluctances of the two flux-paths vary inversely to one another consequent upon a said relative movement taking place. The secondary windings of the stationary transformers are connected serially so that on a variation of the reluctances the potentials appearing across the two secondary windings will differ by an amount corresponding to the relative changes in the reluctances. The said means may be such as either to produce a potential difference to counter the difference between the potentials appearing across the two secondary windings, or whereby a balance of the two secondary circuits may be brought about. For example, in the previous method the means may include two further transformers similar to one another and connected similarly to and having their secondary windings connected in series with those of the stationary transformers. The reluctances of the magnetic circuits of the two further transformers may thus be mutually adjusted inversely to one another until the difference potential produced thereby in the secondary circuit is equal and opposite to the difference potential produced by the stationary transformers. Thus, the extent of the adjustment needed to bring this about is a measure of the said relative movement. In the latter method the secondary windings of the stationary transformers may be serially connected in the same sense with one another and with a potentiometer included in the said means, the said potential difference between the said two points in the secondary circuit being derived between the point between the inductances and the tapping point of the potentiometer. Obviously, any difference of the potentials appearing across the secondary windings may be balanced, as far as the said two points are concerned, by an adjustment of the potentiometer, the extent of any such adjustment being a measure of the differences of the said reluctances and therefore of the relative movement that brought about the difference.

The flux-paths preferably include teeth which project towards each other from ferrous rings secured rigidly to the body at different places therealong, the teeth interlapping with each other in pairs with an air-gap between each pair, a relative movement between the rings consequent on a twist occurring in the body causing the teeth either to move away from or towards one another. The cores of the stationary transformers are coupled to the rings either over radial air-gaps, or air-gaps lying parallel to the body, the latter arrangement particularly allowing for a small radial displacement of the body, such as the whip of a shaft, without affect-

ing the lengths of the coupling air-gaps. Thus a variation of the distances between the pairs of teeth to vary the lengths of the air-gaps therebetween consequent on a relative movement of the rings will bring about a modification of the reluctances of the magnetic circuits of the fixed transformers.

In the accompanying drawings there are illustrated by way of example two different methods of carrying the invention into effect as applied to the measurement of twist along a section of a rotating shaft. In Fig. 1 of the drawings is illustrated a method which involves a straightforward transformer action and which may be used with shafts of any diameter whether or not the shaft has whip, and Fig. 2 illustrates diagrammatically suitable circuit arrangements therefor. Fig. 3 illustrates the other method which involves the use of a double or differential transformer action, and Fig. 4 and Fig. 5 illustrate diagrammatically alterative circuit arrangements for use with this further method.

The method of Fig. 1 will first be described. In Fig. 1 a portion of a hollow horizontal metal shaft is shown at 1. To the shaft 1 at one of the two places therealong between which the torsion is to be measured, that is at the right-hand end as illustrated, is secured a ferrous ring 2 having substantially a rectangular cross-section. The ring 2 is preferably seated on a raised portion 3 of the shaft. The ring may be made in two halves, to enable them to be fitted over the shaft, the ends of the two halves being held as closely as possible in intimate contact. From one side of the ring, the left-hand side as illustrated, projects a number of equi-angularly spaced teeth 4, twelve teeth being provided in the illustration, and therefore they are spaced at 30° apart.

Surrounding, but clearing, a length of the shaft is a rigid non-magnetic metal sleeve 5 which at the end thereof remote from the ring 2 is secured, e.g. by screws, to the shaft at the other of the two places between which the torsion is to be measured. This sleeve may also be in two halves which are securable together by longitudinal flanges to permit its assembly over the shaft. To the free-end of the sleeve 5, adjacent the ring 2, is secured a further iron-ring 6, similar in all respects to the ring 2 except that its laterally projecting teeth 7 project from its right-hand instead of its left-hand side as in the case of ring 2. The annuli 2 and 6 are secured to the shaft 1 and the sleeve 5, respectively, so that their teeth interlap and are positioned together in adjacent pairs with a small air-gap 8 intervening between each pair.

Adjacent to, but separated by an air-gap 10, from the right-hand exterior face of the ring 2, and clearly surrounding the shaft 1, is a ferrous annulus 9 supported from the fixed brackets 11.

A number of open-cored transformers 12 are fixed at one end of their cores to the annulus 9 at equal distances apart, the number of transformers depending *inter-alia*, on the extent of the current or current change which is to occur consequent on relative movements between the two places along the shaft with which the rings 2 and 6 are associated. The length of the cores of the transformers is slightly greater than the distance between the outer faces of the two rings 2 and 6, and to the left-hand ends of the core is fixed a further annulus 13, identical with the annulus 9, and which overlaps, but is separated by a small air-gap from, the outer face of the ring 6, and clears the sleeve 5.

Thus it will be seen that the magnetic circuits of the transformers 12, starting from the right-hand ends of the cores thereof, exist over the annulus 9, air-gap 10, ring 2, and teeth 4 thereof, air-gaps 8, teeth 7 and the ring 6, air-gap 14, annulus 13, to the left-hand ends of the cores. In Fig. 2 this magnetic circuit is indicated by broken lines in the diagrammatic representation of the parts.

The air-gaps 10 with a true running of the shaft will remain of a constant length even should some whip occur, and provide for the coupling between the stationary and rotating parts of the arrangements without friction. On the other hand the air-gaps 8 will have a mean length when the shaft is stationary, providing a mean reluctance of the magnetic circuits of the transformers, whereas if the shaft is driven in a counter-clockwise direction, by a force applied to its left-hand end, a twist in the shaft will occur, and considering the position of the shaft illustrated, the teeth 7 of the ring 6 will move closer to the teeth 4 of the ring 2 resulting in a diminishing of the air-gaps 8 and reduction of the reluctances of the magnetic circuits, the greater the applied force the greater the reduction in the lengths of the air-gaps. Thus with a varying current, such as an alternating or interrupted direct current, in the primary windings of the transformers, the voltage appearing across the secondary windings will be at a mean value when the shaft is stationary, and will increase as the lengths of the air-gaps diminish. The primary windings of the several transformers are connected in series and additively with one another, and the secondary windings are similarly connected.

Referring to Fig. 2. The arrangements

above described are clearly illustrated diagrammatically at the top of the figure. At the lower part of the figure is shown a further open-cored transformer 15, the core of which is shunted by an iron-yoke 16. This iron-yoke 16 is arranged, in any convenient manner, not shown, to be slidable towards and away from the core of the transformer so as to enable the reluctance of the magnetic circuit of the latter to be varied. Engaging with this yoke by a micrometer screw is a spindle 17 which is rotatable, but fixed against longitudinal movement in any convenient manner, and has a graduated drum 22 secured to its other and free end, the drum having a handle attached thereto by which it may be rotated. The primary windings of transformers 12 and 15, as indicated by heavy lines, are connected in series with one another and with a source of direct current 18 and interrupter contacts 19 which are adapted to open and close at a predetermined and constant frequency. The secondary windings of the transformers 12 and 15, as indicated by light lines, are connected in series with each other over further interrupter contacts 20, the circuit also including a differentially reading galvanometer 21. The secondary of the transformer 15, however, is connected so that the potential induced across it will be in opposition to the potential produced across the series connection of secondary windings of transformer 12.

By the interruption of the primary circuit by the interrupter contacts 19, obviously, an alternating potential will appear across the secondary windings of all the transformers, and neglecting other considerations for the present, and with a continuous secondary circuit, an alternating current will appear in the latter. This current could be used to operate an alternating current instrument such as 21. Alternatively, the current could be rectified to operate a direct current instrument. However, as illustrated, the secondary circuit is arranged to be interrupted by the contacts 20 at each alternate half-cycle, so that a pulsating direct current flows in it. The contacts 20 are arranged to be closed prior to the closure, and opened prior to the opening, of the contacts 19. For example assuming the contacts to be operated upon by a rotating cam, both contacts will be closed for one half of a revolution with the contacts 20 being closed first and overlapping the contacts 19 by 90°.

The detailed operations are as follows. Assuming that the shaft is stationary, that the source 18 is connected up, and that the interrupter contacts 19 and 20 are set into operation. The contacts 19 interrupt the primary circuit so that alternating potentials will appear across the secondary windings of all the transformers. The potential across the secondary winding of transformer 15, however, will be in phase opposition to the total potential across the secondary windings of the transformers 12, and should one of the potentials predominate a current will flow in one or other direction in the secondary circuit at each alternate half cycle, that is, at each closure of contacts 20, the value of the current depending on the extent of the difference of the potentials. In order to obtain readings of twist in the shaft it is arranged that when the shaft is stationary these potentials mutually balance one another so that the instrument 21 rests at zero, this being accomplished by adjusting the yoke 16 of the transformer 15, to alter the reluctance of the magnetic circuit of the latter, until the potential across the secondary is equal to the additive potential across the secondaries of the transformers 12. The division of the scale of drum 22 adjacent the fixed pointer, if other than zero, may be noted and selected as the zero, or it is preferred that the drum 22 is adjusted independently of the spindle 17 until it reads zero and then again fixed to the shaft.

Assuming that a turning force is applied to the left hand end of the shaft such as to turn the latter in a counter-clockwise direction, then the shaft will twist in a manner such as to cause the teeth 7 and 4 to approach each other and decrease the lengths of the air gaps 8. This will reduce the reluctance of the magnetic circuits of the transformers 12 with a result that the additive potential across the secondary windings will rise and thus exceed that across the secondary winding of transformer 15. A current corresponding to the difference in potentials will flow in the secondary circuit and bring about a deflection of the instrument 21 from its zero position. A balance of the potentials is again established by rotating the drum 22 to turn the spindle 17 whereby the yoke 16 is caused to approach more closely to the core of the transformer 15 to decrease the reluctance of the magnetic circuit thereof so that the potential across the secondary of the latter transformer increases, the adjustment being continued until the potentials are balanced as will be indicated by the instrument 21 reading zero. The amount of adjustment of the yoke 16 again to establish a condition of balance is similar to the respective movements of the teeth 4, 7, brought about by the twist, and is thus a measure of the twist, and the extent of this adjustment is indicated by the divisions of the scale

of the drum 23 passed through to bring the instrument 21 back to zero, or the selected zero indication. From the reading given by the scale of the drum 22 together with other factors, the torque in the shaft and horse-power applied to it can be calculated in known manner.

Any variation in the twist of the shaft will be indicated by a deflection of the instrument 21 in an appropriate direction from its zero position, and an adjustment can be effected as before to obtain an indication of the prevailing amount of twist. If the twist of the shaft decreases or if the shaft has been rotated in the opposite direction, i.e. the power being applied to the left-hand end of the shaft in the clockwise-direction, the teeth 4 and 7 would tend to move away from one another and obviously the reading on the instrument 21 would be on the opposite side of zero to that obtained when the teeth approach one another. A condition of balance would be re-established and an indication of the amount of twist obtained in a manner similar to that previously described.

The arrangements of Fig. 1 are particularly suitable for the measurement of twist along a length of shaft near a bearing where the brackets 11 can be secured to the fixed part of the bearing. The sleeve 5 must be rigid, and, obviously, if the places along the shaft between which the twist is to be measured calls for a length of sleeve too great to ensure its rigidity, the ring 2 could also be secured to a length of sleeve.

The arrangements illustrated in Figs. 3, 4 and 5 will now be described.

In Fig. 3, a section of the shaft is shown at 23, and about but clearing the shaft are two non-magnetic sleeves 24 and 25, which at their opposite extremities are secured respectively to the shaft at the places between which the twist is to be measured. To the free end of the sleeve 24, opposite to the free end of the sleeve 25, is secured a cylindrical iron ring 26 having a number of teeth 27, equally spaced apart, projecting from its left-hand end and lying parallel with the sleeve and shaft. In the arrangement illustrated twelve such teeth are provided. Similarly, there is secured to the free end of the sleeve 25 an iron ring 28, similar in all respects to the ring 26 except that the teeth 29 project from the right-hand side towards the ring 26. Midway between the rings 26 and 28 and secured to the shaft is a further cylindrical iron ring 30. This latter iron ring 30 has teeth equal in number to the teeth projecting from the rings 26 and 28, projecting from both of its ends, the teeth 31 projecting from its right-hand end interlapping with the teeth 27 of the ring 26, whereas the teeth 32 projecting from the left-hand end interlap with the teeth 29 of the ring 28. The rings 26, 28 and 30, are so positioned that the teeth of the latter are each positioned adjacent the teeth of the former, so that the teeth cooperate in pairs. Thus the teeth 27 cooperate with the teeth 31 to form pairs, there being an air gap 33 between the teeth of each pair, whereas the teeth 29 cooperate with the teeth 32 to form pairs, there being an air-gap 34 between each pair.

Surrounding the rings 26, 28 and 30, is a casing of iron, which casing comprises an outer cylindrical shell 35 having secured internally thereto and at each end thereof an iron annulus having its inner periphery turned inwards at right-angles to form short cylinders. These annuli are designated 36 and 37, and the cylindrical portions thereof are of the same length as and coincide with the rings 26 and 28 respectively, and have a diameter slightly greater than the said rings so that air-gaps 38 and 39 exist between them. Obviously a regular annulus, such as the annulus 9, Fig. 1, could be used so that the air-gaps shall lie parallel to the shaft. At the middle of the cylindrical shell 35 there depends from a web 40, a cylinder 41 having a length corresponding to the length of, and which coincides with, the ring 30 secured to the shaft, there being a small clearance between the inner surface of the cylinder 41 and exterior surface of the ring 30 to form an air gap 42. The web 40 thus divides the casing into two compartments, one to the right and one to the left of it. Within the right-hand compartment is contained the primary winding 43 and the secondary winding 44 of a transformer, and in the left-hand compartment is contained the primary winding 45 and secondary winding 46 of a further transformer, a packing of insulating material being interposed between the casing and the windings and between the windings themselves as indicated. A lug (or lugs) 47 depends from the shell 35 which is bolted to a fixed bracket 48. The primary windings of the transformers have, as far as possible, identical characteristics, which also applies to the secondary windings.

It will be seen that the casing provides a portion of the magnetic circuits for the two transformers, and in particular the magnetic circuit for the right-hand transformer 43, 44 exists over the annulus 36 and its cylindrical portion, air-gap 38, ring 26 and teeth 27 thereof, air-gaps 33, teeth 31 and ring 30, air-gap 42, cylinder 41, web 40, and shell 35. The magnetic

circuit for the left-hand transformer 45, 46, similarly exists over annulus 37 and the cylindrical portion thereof, air-gap 39, ring 28 and teeth 29 thereof, air-gaps 34, teeth 32 and ring 30, air-gap 42, cylinder 41, web 40, and shell 35. Obviously, the primary windings 43 and 45 should be so connected in circuit that the fluxes of the two transformers pass in the same direction through the web 40 which provides a common path for both fluxes.

With this arrangement it will be seen that when a twisting force is applied to the shaft 23 the air-gaps 38 and 39 will remain constant, but the lengths of the gaps 33 and 34 will vary conversely. For example, if a twisting force is applied to the left-hand end of the shaft such as to turn it in a counter-clockwise direction, then considering the section at the ends of which the sleeves 25 and 24 are fixed, the latter end will lag behind the former end. The cylinder 30 being situated midway between these ends is in effect, situated at the node of the length of twist being considered and in consequence the teeth 29 will tend to move away from the teeth 32 and therefore increase the air-gaps 34, resulting in an increase in the reluctance of the magnetic circuit of the transformer 45—46 and reduction of any induced potential across the secondary winding 46, whereas the teeth 27 will lag behind the teeth 31 resulting in a reduction in the length of the air-gaps 33 whereby the reluctance of the magnetic circuit of the transformer 43—44 is decreased and a corresponding increase of any potential induced across the secondary 44 will occur.

Referring to the circuit arrangement illustrated in Fig. 4. The arrangements above described are illustrated diagrammatically at the top of the figure and will be understood without further description.

At the bottom of the figure are shown two open cored transformers 49 and 52 having similar characteristics to one another and to the other fixed transformers, the transformers 49 having primary and secondary windings 50 and 51 respectively, whilst corresponding windings of transformer 52 are designated 53 and 54. The two transformers are fixed at a distance apart with their cores lying parallel to each other, and between the transformers is a common piece 55 of iron which is adapted to bridge the ends of both of the cores, and thus complete the magnetic circuits, of both transformers over intervening air-gaps. The bridging piece is arranged to be slidable and guided in any convenient manner between the transformers so that it can be brought closer to one than the other, the sliding motion being imparted to it by means of a projection 56 therefrom which is engaged, through a micrometer screw thread, with a spindle 57 rotatable by a graduated drum 58, but which spindle is restrained against longitudinal movement. Thus in this arrangement with the bridging piece 55 midway between the transformers, the reluctances of their magnetic circuits will be similar and consequently with the same value of fluctuating current passing through the primaries potentials of similar values will appear across the secondaries. If, however, the bridging piece 55 is moved more closely to one transformer than the other, the respective reluctances will decrease and increase with a corresponding increase and decrease of the potentials appearing across the secondaries.

The primary windings 43, 45, 50 and 53 of the several transformers are all connected in series with one another and with a source of direct current 62 and interrupter contacts 59, which latter, as in the case of Fig. 2, are caused to open and close at a predetermined constant frequency. The secondary windings 44, 46, 51 and 54 are also connected in series with one another and with interrupter contacts 60, and a differential galvanometer 61. As in Fig. 2, the interrupter contacts 60 are caused to operate to disconnect the secondary circuit at each alternate half-cycle of the current induced into the secondary windings of the transformers.

The secondary windings 44 and 46 are connected in opposite senses to one another, so that the potentials produced across them will be in phase opposition, and this also applies to the secondary windings 51 and 54, and, say, voltages of similar senses appear across secondaries 46 and 51, and across the secondaries 44 and 54, respectively.

Considering the operation of the arrangements in detail. Initially, whilst the shaft is stationary the source 62 is connected up and the interrupter contacts 59 and 60 set into operation. As a result impulses of current flow through the primary windings of all the transformers, and potentials will therefore appear across all of the secondaries. If the air-gaps 33 and 34 are the same, resulting in the reluctances of the iron circuits of the transformers 45, 46, and 43, 44, being similar, voltages of similar values but in phase opposition will be induced across the secondary windings 44 and 46, and assuming the transformers 49 and 52 are similarly balanced the voltages will cancel each other and no current will appear in the secondary circuit, and thus the instrument 61 will read zero.

If there is a slight unbalance between

the transformers 43, 44, and 45, 46 by reason of a small difference between the air-gaps 33 and 34, then the potential across one secondary will be preponderant and a current will flow in the secondary circuit to influence the instrument 61 to move to one or other side of its zero. In this case, the bridging piece 55 is moved in the appropriate direction between the transformers 49 and 52 until the potential across one of the secondaries 51, 54 preponderates to produce a current equal and opposite to that produced as the result of the unbalance of the transformers 43, 44, and 45, 46, which condition is indicated by the instrument 61 giving a zero reading. The reading on the drum may be selected as the zero, but on the other hand it is preferable to adjust the drum 58 independently of the shaft 57 until its zero division is adjacent the fixed pointer and is then again secured to the shaft. Thus the arrangements are adjusted to give a zero reading in the absence of torque.

Assuming that the shaft is set into counter-clockwise rotation by a force applied to its left-hand end, then as before referred to the length of the air-gaps 34 between the teeth 29 and 32 will increase, and a corresponding decrease will take place in the lengths of the air-gaps 33 between the teeth 27 and 31. This results in an increase in the reluctance of the iron circuit of transformer 45—46, with a consequential decrease in the potential appearing across the secondary 46, and a corresponding decrease in reluctance of the iron circuit of transformer 43—44 with a consequential increase of the potential appearing across the secondary 44. Thus the potentials across the secondaries 44 and 46 become unbalanced and a current of a value dependent on the amount of unbalance will flow in the secondary circuit and the instrument 61 will give a corresponding reading.

The drum 58 is turned in a direction such as to cause the bridging piece 55 to approach more closely to the transformer 49 whereby the reluctance of the iron circuit of this transformer is reduced to increase the potential across the secondary winding 51, and whereby the reluctance of the iron circuit of transformer 52 is increased with a consequential lowering of the potential appearing across its secondary 54. This adjustment is continued until the instrument 61 indicates zero indicating that a balanced condition of potentials is again established in the secondary circuit. Thus the amount of movement of the bridging piece 55 necessary to re-establish the condition of balance corresponds to the respective movements of the teeth 29 and 32 and 27 and 31, and therefore to the amount of twist along the section of the shaft under consideration, and the extent of the adjustment is indicated to the operator by the number of divisions of the scale on the drum 58 passed over in order to restore the instrument 61 to give a zero reading. From this and other factors the torque and applied horse power can be calculated in known manner.

The arrangements of Fig. 5 differ from those of Fig. 4, in that instead of the establishment of an electromagnet balance of the outputs of the transformer, the balance is effected purely electrically by a bridge method of balancing. In this figure similar designations are used to indicate parts corresponding to like parts in Fig. 4.

In Fig. 5 the two transformers 43—44 and 45—46 are arranged as in Fig. 4, and have their primary windings 43 and 45 connected in series with one another and with a source of potential and interrupter contacts 59 whereby their circuit is interrupted at a constant frequency. The secondary windings are connected in series with one another, and in the same sense, so that voltages appearing thereacross are added, and with a potentiometer 63. A galvanometer 61 is connected from between the two windings to the tapping point of the potentiometer which is movable to and fro by means of a spindle and drum (not shown), but which will correspond to the spindle 57 and drum 58 of Fig. 4. It is obvious that the potentiometer can be adjusted to a point along it at which the potential will equal that appearing at the point between the secondary windings so that the instrument will give a zero reading. If the relative potentials across the secondary windings alter by reason of a twist or alteration of twist being set up in the shaft, then the potential at the point between the secondaries will alter and become different from that at the tapping point of the potentiometer with a consequence that current will flow through the instrument 61. The extent of the adjustment of the potentiometer necessary to re-establish a balance of the two potentials under consideration will be a measure of the amount of twist or variation of twist, and as in the previous examples will give one of the factors necessary to compute the torque and applied horse-power in known manner.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A torsionmeter for measuring the torque of a shaft comprising a stationary open core transformer adjacent the shaft

the magnetic circuit of which is completed over members on the shaft and an air-gap or gaps and in which the reluctance of the magnetic circuit varies with the torque to produce a potential difference or change of potential difference between two points in the circuit of the secondary winding of the transformer, and manually or otherwise adjustable means for nullifying said potential difference or change of potential difference, the extent of movement of said adjustable means being a measure of the torque of the shaft.

2. A torsionmeter according to Claim 1 in which said means includes a further transformer having its primary winding traversed by a varying current in phase with the current in the primary winding of the stationary transformer, and its secondary winding serially connected with but in opposite sense to the secondary winding of the stationary transformer, and wherein the reluctance of the magnetic circuit of the said further transformer is adjustable to correspond with any change in reluctance of the magnetic circuit of the stationary transformer whereby the potential difference across the secondary winding of the further transformer can be rendered of the same value as but of opposite polarity to the potential appearing across the secondary winding of the stationary transformer.

3. A torsionmeter according to Claim 1 in which there are provided two stationary transformers of similar characteristics having their primary windings similarly energised and their secondary windings serially connected with one another, the magnetic circuits for the two transformers being completed over separate flux-paths associated with the shaft, each of which paths includes an air-gap, the lengths of the said two air-gaps being caused to vary inversely to one another as a result of a said relative movement to cause an inverse variation of the values of the relative potentials appearing across the two secondary windings.

4. A torsionmeter according to Claim 3 in which the secondary windings of the two stationary transformers are connected to act in opposition to one another, and said means includes two further transformers identical with one another and having their primary windings fed by currents similar to those traversing the primary windings of the stationary transformers and their secondary windings connected differentially but in series with one another and serially with the secondary windings of the stationary transformers, and in which the magnetic circuit of each of the two further transformers includes an air-gap, which two air-gaps are variable inversely to one another to vary the reluctances of the respective magnetic circuits and therefore the potentials appearing across the secondary windings thereby to produce a difference potential to counter the potential applied to the said two points from the secondary windings of the stationary transformers.

5. A torsionmeter according to Claim 2 or 4 in which the magnetic circuit of the further transformer or the magnetic circuits of the two further transformers are completed over a magnetic bridging piece bridging the ends of the core or cores of the further transformer or transformers, the bridging piece being movable through the medium of a screw connection from a graduated indicator to or away from the core of the further transformer or between the cores of the two further transformers.

6. A torsionmeter according to Claim 3 in which the secondary windings of the two stationary transformers are serially connected in similar senses with one another and with a potentiometer included in said means, the said two points to which a potential is applied consisting of the point between the two secondary windings and the tapping point of the potentiometer.

7. A torsionmeter according to Claim 6 in which the tapping point of the potentiometer is adjustable from a graduated indicator through the medium of a screw-connection.

8. A torsionmeter according to Claim 1, 2 or 3 in which the core of a stationary transformer is coupled to the said flux-path over an air-gap lying parallel to the adjacent surface of the shaft.

9. A torsionmeter according to Claim 8 in which the said flux-path includes a pair of ferrous rings secured to the shaft, one at each of said places, each of said rings being provided with teeth facing towards the other ring, the teeth on the two rings interlapping with one another and co-operating in pairs, there being an air-gap between the teeth of each pair, and wherein a ferrous annulus associated with one end of the core of the stationary transformer surrounds but clears said shaft and overlaps but is separated by an air-gap from, one of said rings, the other end of the core of the transformer being magnetically coupled to the other of said rings.

10. A torsionmeter according to Claim 1 substantially as described and as illustrated in Fig. 1 of the accompanying drawings.

11. A torsionmeter according to Claim 1 and circuit arrangements therefor substantially as described and illustrated in Figs. 1 and 2 of the accompanying drawings.

12. A torsionmeter according to Claim 1 substantially as described and illustrated in Fig. 3 and circuit arrangements therefor substantially as described and illustrated in Fig. 4 or Fig. 5.

Dated this 8th day of February, 1946.
SIEMENS BROTHERS & CO. LIMITED.
By their Attorney,
F. A. LAWSON.
For Selves and Co-Applicant.

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588,677 COMPLETE SPECIFICATION

SHEET 1

[This Drawing is a reproduction of the Original on a reduced scale.]

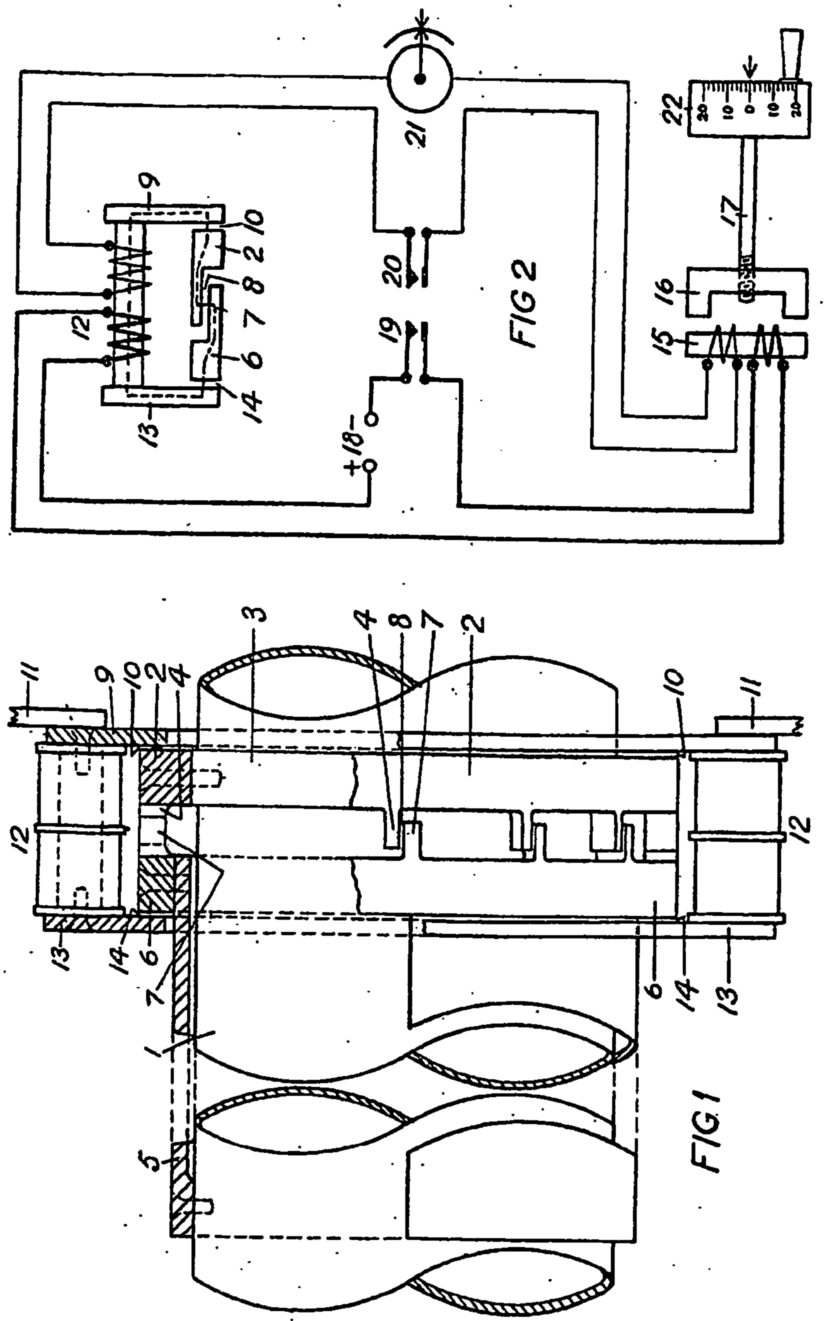
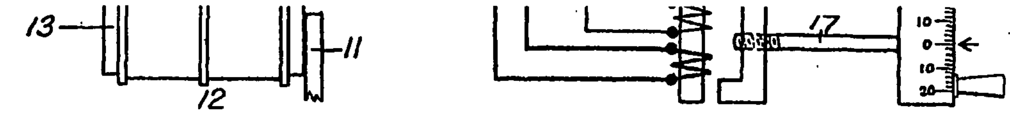


FIG 2

FIG 1

FIG 1



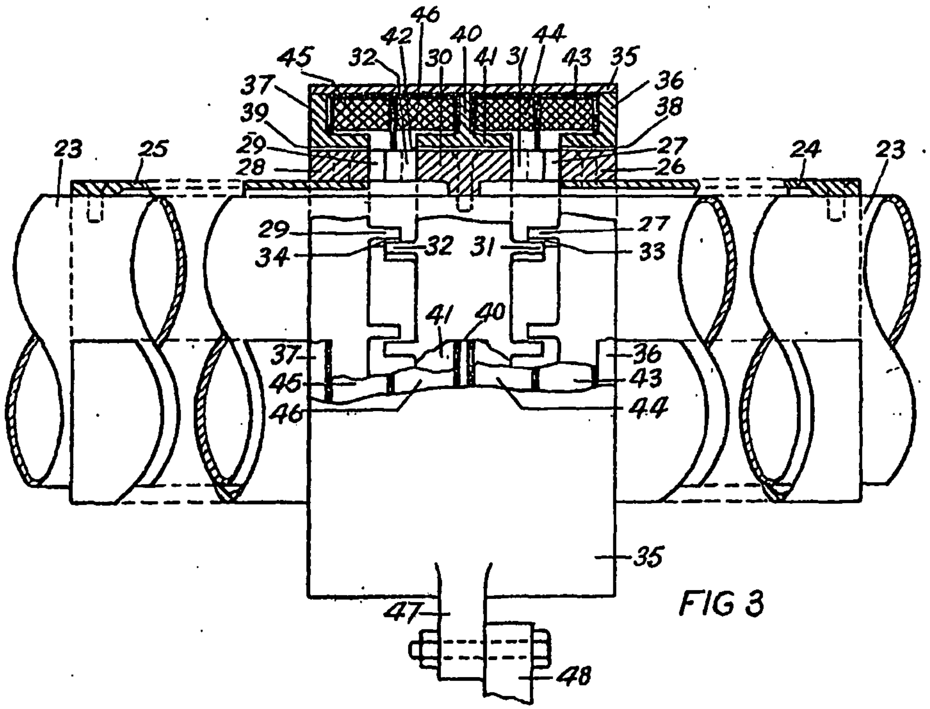


FIG 3

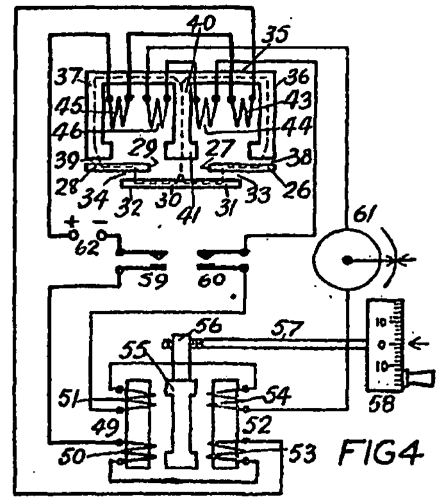


FIG4

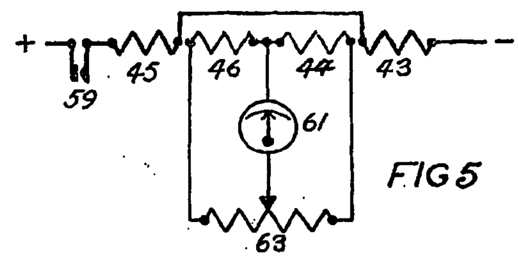


FIG 5

H.M.S.O. (Ty. P.)

[This Drawing is a reproduction of the Original on a reduced scale]

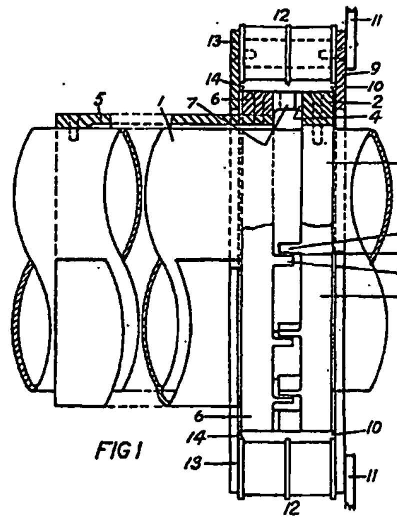


FIG 1

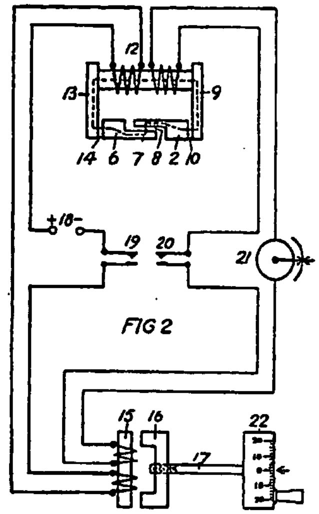


FIG 2

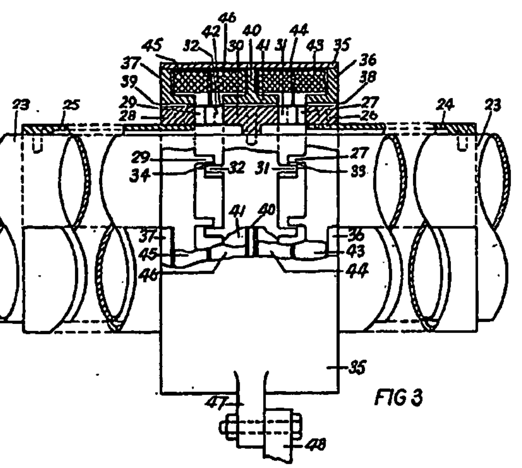


FIG 3

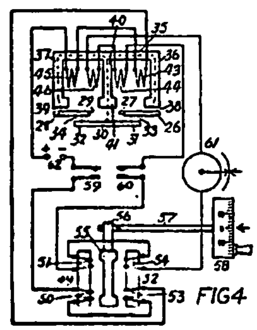


FIG 4

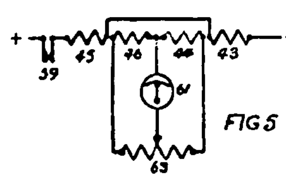


FIG 5

H.M.S.O.(Ty.P.)